Economic Performance of Alternative Tillage Systems in the Northern Corn Belt

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ABSTRACT

While no-till (NT) cropping systems can provide conservation benefits in the northern Corn Belt, adoption has been low due to concerns about potential yield reductions and economic risk. Strip-tillage (ST) systems have been proposed as an alternative that may provide many of the conservation benefits of NT while maintaining productivity and economic returns. The objectives of this study were to evaluate the effects of NT and five ST alternatives: fall residue management (Fall RM), Fall RM + ST, spring residue management (Spring RM), Spring RM + ST, and Fall RM + Subsoil, relative to conventional moldboard plow (MP) and chisel plow (CP) tillage systems on corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] yields and economic risks and returns. Average yields over the 7-yr study were not significantly different among tillage systems, but average net returns for NT, Fall RM, and Spring RM were $85, 92, and 53 ha^{-1} higher, respectively, than for MP. Risk analysis showed tillage system preferences ranked as: Fall RM > NT > Fall RM + ST > Spring RM + ST, Spring RM > CP > Fall RM + Subsoil > MP for risk neutral or risk averse producers facing uncertain yield, crop price, and input price conditions. Thus, ST and NT may be economically viable alternatives to conventional tillage systems for corn and soybean production in the northern Corn Belt.

ALTHOUGH NO-TILL has been successful in warmer, drier areas, there are continued challenges with its use on heavy soils in cool, wet areas of the U.S. northern Corn Belt. From 1994–2004, NT adoption has ranged from 2.5 to 3.8% of planted cropland in Minnesota (CTIC, 2008), where use of intensive tillage, including MP tillage is common (Napier and Tucker, 2001). Strip tillage has been developed as an alternative that may provide many of the conservation benefits of NT while maintaining productivity and economic returns (Vetsch and Randall, 2002; Vetsch et al., 2007). Effects of tillage on crop yields in a corn and soybean rotation vary considerably. Yield reductions have often been noted for NT relative to MP or CP treatments, particularly for soils with root-restricting tillage pans (Camp et al., 1984; Busscher et al., 2006) or for poorly drained soils and cool climates (Archer et al., 2008; Brown et al., 1989; Chase and Duffy, 1991; West et al., 1996; Vetsch and Randall, 2004; Al-Kaisi and Yin, 2004). Strip till-age systems were developed for use in the Southeastern United States as a method to manage soil compaction in Coastal Plain soils by combining deep tillage with crop residue cover (Harden et al., 1978; Busscher and Sojka, 1987). Strip tillage systems were proposed for cooler, wetter locations based on observations that removal of crop residue from a strip over the row may increase early-season soil temperatures and subsequent corn yields (Kaspar et al., 1990). For Coastal Plain soils in the Souteastern United States, ST generally results in higher yields than conventional tillage (Edwards et al., 1988; Ewing et al., 1991; Hunt et al., 2004). However, observed yield impacts for ST systems in the northern Corn Belt have been inconsistent. Vetsch and Randall (2004) observed ST corn yields were intermediate to and not significantly different from CP and NT corn yields in a corn-soybean rotation in south-central Minnesota. Vyn and Raimbault (1992) observed lower corn yields under ST than MP on silt loam and clay loam soils for a continuous corn system in Ontario; however, ST resulted in yields not significantly different from CP and higher than NT for some years on a sandy loam soil. Al-Kaisi and Licht (2004) observed that a fall ST treatment resulted in higher corn yield than NT for one of four site-years in Iowa.

Similar to grain yields, the economic performance of corn and soybean under NT varies with soil type and climate conditions, with generally better performance noted for well-drained soils and warmer climates (Yin and Al-Kaisi, 2004; Al-Kaisi and Yin, 2004; Pendell et al., 2006), and poorer performance for poorly drained soils and cooler climates (Yin and Al-Kaisi, 2004; Al-Kaisi and Yin, 2004; Yiridoe et al., 2000; Chase and Duffy, 1991). Vetsch et al. (2007) observed NT and ST net returns were comparable with net returns under full-width tillage systems for a tile-drained clay loam soil in south-central Minnesota. However, effects of tillage system on economic risk were not evaluated in the foregoing analyses. Klemme (1985) evaluated economic risk for MP, CP, NT, and ridge-till systems for a corn-soybean rotation in Indiana, showing that MP and CP dominated NT for all risk-averse producers unless

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Abbreviations: CE, certainty equivalent; CP, chisel plow; Fall RM, fall residue management; LDP, loan deficiency payment; MP, moldboard plow; MVE, multivariate empirical distribution; NT, no-till; RA, risk aversion; SERF, stochastic efficiency with respect to a function; Spring RM, spring residue management; ST, strip-tillage.

substantial soil loss costs were included. However, the risk analysis did not include effects of crop and input price changes. Also, the analysis did not include ST alternatives and technological changes that have occurred since that time, including the availability of herbicide-resistant crops. Yiridoe et al. (2000) evaluated economic risk for seven tillage system treatments in a corn-soybean rotation in Ontario, and observed that the MP tillage system dominated all other tillage alternatives, including CP, ST, and NT, for all risk-averse producers. However, the risk analysis was based on a limited set (3 yr) of yield observations, and thus may not adequately reflect the risks associated with each tillage treatment.

Moldboard plowing releases large amounts of CO_2 to the atmosphere (Reicosky and Lindstrom, 1993), while forms of NT and ST release substantially less CO_2. Conversion of cropland from MP tillage to less-intensive tillage systems would also reduce the potential for soil erosion, thus adoption of less-intensive tillage systems could reduce CO_2 emissions and environmental impact (Reicosky, 1998). While a complete accounting of the economic impacts to society would include valuation of these environmental impacts, our focus is on the direct economic impacts at the farm level, since this is what is relevant to the farm manager and the decision to adopt less-intensive tillage practices. Thus, our objective was to compare the agronomic and production-related economic performance of NT and ST alternatives to conventional MP and CP tillage systems for a corn-soybean rotation, on heavy soils in the northern Corn Belt.

METHODS AND MATERIALS
Field Study

A ST residue management study was established at the USDA-ARS Swan Lake Research Farm (45°41′ N, 95°48′ W, elevation 365 m) near Morris, MN, in 1997. Annual precipitation in this region averages 645 mm and average monthly temperatures range from –13.1°C in January to 21.7°C in July (NOAA-NCDC, 2002). The study site includes six mapped soil series: Aastad clay loam (fine-loamy, mixed, superactive, frigid Pachic Argiudoll), Barnes loam (fine-loamy, mixed, superactive, frigid Calcic Hapludoll), Flom silty clay loam (fine-loamy, mixed, superactive, frigid Typic Endoaquoll), Hamerly clay loam (fine-loamy, mixed, superactive, frigid Aeric Calciaquoll), Parnell silty clay loam (fine, smectitic, frigid Vertic Argiaquoll), and Vallers silty clay loam (fine-loamy, mixed, superactive, frigid Typic Calciaquoll). These soil series have similar physical and chemical properties characteristic of soils derived from glacial till, and as a result, have only subtle differences. The soils are imperfectly drained with random tile drainage from the depressions within the experimental area.

The 7-yr study included a corn-soybean (C-S) rotation with eight tillage system treatments initiated in the spring 1997. Plots were established in a randomized complete block design with crop and tillage main factors with each crop present each

Table 1. Schedule of field operations for each tillage treatment.†

Operation	Month	NT	MP	CP	Fall RM	Fall RM + ST	Spring RM	Spring RM + ST	Fall RM + Subsoil
Corn									
MP	Sept.–Oct.		×						
CP	Sept.–Oct.			×					
Fall RM	Sept.–Oct.				×				
Fall RM + ST	Sept.–Oct.					×			
Fall RM + Subsoil	Sept.–Oct.								×
Field cultivate	Apr.–May		×	×					
Spring RM	Apr.–May						×		
Spring RM + ST	Apr.–May							×	
Plant	Apr.–May	×	×	×	×	×	×	×	×
Broadcast fertilizer	June	×	×	×	×	×	×	×	×
Spray herbicide	June	×	×	×	×	×	×	×	×
Harvest	Sept.–Oct.	×	×	×	×	×	×	×	×
Soybean									
Disk	Sept.–Oct.		×	×					
MP	Sept.–Oct.		×						
CP	Sept.–Oct.			×					
Fall RM	Sept.–Oct.				×				
Fall RM + ST	Sept.–Oct.					×			
Fall RM + Subsoil	Sept.–Oct.								×
Field cultivate	Apr.–May		×	×					
Spring RM	Apr.–May						×		
Spring RM + ST	Apr.–May							×	
Plant	Apr.–May	×	×	×	×	×	×	×	×
Broadcast fertilizer	June	×	×	×	×	×	×	×	×
Spray herbicide	June	×	×	×	×	×	×	×	×
Harvest	Sept.–Oct.	×	×	×	×	×	×	×	×

† NT, no-till; MP, moldboard plow; CP, chisel plow; Fall RM, fall residue management; Spring RM, spring residue management; ST, strip-tillage.

year and with five replicates. The plot size was 9.1 m wide (12 rows, 76 cm row spacing) by 27.4 m long. Tillage treatments included NT, MP, CP, and five ST alternatives: Fall RM, Fall RM + ST, Spring RM, Spring RM + ST, and Fall RM + Subsoil. The general schedule of field operations for each treatment is listed in Table 1.

The NT treatment had no tillage other than planting for both corn and soybean. In the MP treatment and CP treatments, corn stalks were disked after harvest, but before other fall tillage. In the MP treatment, both corn and soybean plots were moldboard plowed in the fall and field cultivated in the spring before planting. Moldboard plow tillage was accomplished with a conventional 0.46-m-wide four-bottom Case IH (Racine, WI)[1] plow (Model 500) that inverted the soil to a depth of 25 cm. The moldboard plow was pulled with an 80-kW tractor at about 7 to 8 km h^{-1} to mimic large field operations. Field cultivation was accomplished with a 3-m-wide Willrich (Model 2500) field cultivator with sweep-type tools on chisel spring-shanks tilling to a depth of 7 to 10 cm. In the CP treatment, both corn and soybean plots were tilled with a

3.66-m-wide John Deere (Moline, IL) chisel plow (Model 610) to a depth of 15 to 20 cm in the fall and field cultivated in the spring before planting. In the Fall RM treatment, a Yetter L 128 fertilizer row unit with a 13-wave coulter that penetrated 7.6 cm and two residue managers (spoked wheels) that moved the surface residue and loosened the surface 1 cm deep and about 10 cm wide over each row (Reicosky, 1998), was used in the fall for both corn and soybean. Crops were planted into the cleared strips in the spring. The Fall RM + ST treatment was the same as Fall RM with the addition of a Mole Knife (Hi-Pro Manufacturing, Watseka, IL) attached to the row unit with a 0.95-cm shank that loosened the soil to 15 cm deep in a U-shaped volume with the upper surface 15 to 17 cm wide. The Mole Knife had a foot 3.8 cm wide that caused a loose, open cylindrical area at the bottom of the loosened soil and can be used to incorporate liquid or granular fertilizer (although no fertilizer was applied with the knife in this study). The Spring RM treatment was the same as Fall RM, but the ST operation was conducted in the spring before planting. The Spring RM + ST treatment was the same as Fall RM + ST, but the ST operation was conducted in the spring before planting. The Fall RM + Subsoil treatment was the same as Fall RM with the addition of a low disturbance Yetter subsoil shank that penetrated to 35 cm deep. The subsoil shank was 3.2 cm wide with a 5.1-cm wide foot and loosened the soil in the form of a narrow triangle or 'V' form about 18 to 20 cm wide at the surface. The Fall RM + Subsoil treatment left soil clods that were larger than the other forms of ST because of the deep penetration that left a rough surface. All ST tools were followed by closing discs set to mound the soil over the row.

Planting and harvest dates and seeding rates were the same for all tillage treatments. A four-row Hiniker (model Econo-till-3000) planter was used in 1997–1999, and a four-row John Deere (model 1730) planter was used in 2000–2003 in planting all treatments. Corn seeding rates were 84,000 and 85,000 seeds ha^{-1} in 1997–1999 and 2000–2003, respectively. Corn seed variety was Pioneer 37M81 in 1997, and Pioneer 38W36 (Bt) in 1998–2003. Soybean seeding rates were 470,000 and 490,000 seeds ha^{-1} in 1997–1999 and 2000–2003, respectively. Soybean seed variety was Pioneer 9091 in 1997 and NK14-M7 (RR) in 1998–2003. Herbicide applications were the same across tillage system treatments within each year. For soybean, in-season weed control was accomplished with one herbicide application of 1.7 kg a.i. ha^{-1} glyphosate [*N*-(phosphonomethyl)glycine]. For corn, in-season weed control was accomplished with one application of 0.16 kg a.i. ha^{-1} nicosulfuron {2-[(4,6-dimethoxypyrimidin-2-ylcarbamoyl)sulfamoyl]-N,N-dimethylnicotinamide}. Weed control was generally judged to be good, with no apparent differences among tillage systems. Fertilizer was applied to all plots through the planter, at rates of 20–23–43 kg ha^{-1} of N–P–K in 1997–1999 and 11–17 kg ha^{-1} N–P in 2000–2003. Additional N fertilizer as NH_4NO_3 was broadcast on corn after planting at rates of 168, 224, 216, 224 kg ha^{-1} N in 1997, 1998, 1999, and 2000–2003, respectively, and K fertilizer was mixed and applied at a rate of 22 kg ha^{-1} with the additional N in 2000–2003.

Economic Analysis

Machinery costs were calculated using an engineering approach and 2007 machinery cost data included in the Machdata spreadsheet (Lazarus and Selley, 2007). Machinery complement was selected for a farm size of 405 ha of crop land in a corn-soybean rotation. Machinery depreciation, repair, and ownership costs were calculated based on total annual usage for each piece of equipment for a farm this size. This farm size represents the average commercial farm size for Stevens County, Minnesota, excluding farms with <89 ha, which account for only 5% of farmland in the county (USDA-NASS, 2004). Strip-tillage implement purchase costs were obtained from equipment dealers. For each tillage implement, power requirements were estimated following ASAE methods (American Society of Agricultural and Biological Engineers, 2006) based on the tillage depth and speed used in the field. Following Lazarus and Selley (2007), a labor cost of $15.00 per hour was used for all field operations. Costs for drying fuel use were based on measured grain moisture content at harvest and estimated fuel quantities needed to dry corn to a moisture content of 155 g kg^{-1} and soybean to a moisture content of 130 g kg^{-1}, assuming LP drying fuel usage rate of 2.98 L Mg^{-1} to dry grain 10 g kg^{-1}. Seed, herbicide, and fertilizer costs were based on 2000–2003 actual application rates.

To focus on productivity impacts, and for consistency with other tillage system economic analyses (Vetsch et al., 2007), comparisons of average net returns were conducted holding crop and input prices constant. However, because results may be sensitive to price assumptions, two price scenarios were analyzed: (i) using 2007 crop prices and 2008 diesel, LP, seed, fertilizer, and herbicide prices, and (ii) using 2003–2007 average crop, diesel, LP, seed, fertilizer, and herbicide prices. In both scenarios, all other costs (machinery, labor, interest) were based on 2007 prices. Annual prices for corn and soybean were Minnesota season average prices (USDA-NASS, 2008c). Prices for diesel fuel, LP, seed, fertilizer, and herbicides were annual averages (USDA-NASS, 2001, 2007) except for 2007 and 2008 prices, which were from April 2007 and 2008, respectively (USDA-NASS, 2008a). All prices were adjusted to 2007 dollars using the Producer Price Index (Bureau of Labor Statistics, 2008). Land and management costs were not included in the net return calculations, so net returns represent returns attributable to use of the land and the operator's management.

Risk analysis was conducted using SIMETAR (Richardson et al., 2006) to simulate net return distributions using multivariate empirical distributions (MVEs) of crop yields, grain moisture content at harvest, crop prices, and LP and diesel fuel prices. These variables were selected as key variables that could differ across tillage system treatments. Ideally, risk analysis would include all sources of variation including seed, herbicide, and fertilizer costs. However, these variables did not differ across tillage systems, and given the large number of variables and limited number of observations, they were excluded to facilitate correlation estimation among the remaining variables as discussed below. The MVEs were estimated using 1997–2003 annual yield and moisture content observations, and 1997–2008 annual prices for corn, soybean, diesel, and LP.

The MVE distribution avoids imposing a specific distribution on the variables and is recommended in situations where

the limited number of observations does not allow testing the fit of standardized probability distributions (Richardson et al., 2000). Estimated MVEs include estimated means with deviations calculated relative to either the estimated means or relative to estimated trends expressed as a fraction of each variable. Ideally, MVEs include correlations among each of the variables. However, due to the large number of variables and limited number of observations in this analysis, it was not possible to estimate a complete correlation matrix among all of the variables. Instead, MVEs were estimated for the NT treatment corn and soybean grain yields; and corn, soybean, diesel, and LP prices with deviations calculated relative to the means for each of these variables. Distributions for the other corn grain treatment yields and grain moisture contents were estimated using linear trend estimates relative to NT corn grain yields and annual deviations from this trend, and including correlations among the deviations. Similarly, distributions for the other soybean grain treatment yields and grain moisture contents were estimated using linear trend estimates relative to NT soybean grain yields and annual deviations from this trend, and including correlations among the deviations. While historical prices were used in estimating the MVEs, 2007 crop prices and 2008 input prices were used to represent expected prices in the simulation risk analysis. This approach is consistent with other farming systems risk analyses (Watkins et al., 2008; Ribera et al., 2004), and reflects an assumption that 2007 and 2008 prices better represent current farmer price expectations but that future price variability will be consistent with historical price variability. The limitations of this approach should be noted. Results may differ if future price levels and variability are not consistent with 2007 and 2008 price levels and historical price variability. To test the sensitivity of the risk analysis results to the expected crop and input price assumptions, the risk simulation was repeated with expected crop and input prices set at 2003–2007 average levels. The risk simulation in this work included 1000 iterations of yield and price samples drawn from the estimated MVEs. Testing the results using different random number seeds showed that 1000 iterations were sufficient for results to be consistent among simulations (data not shown).

Net return calculations in the risk analysis included simulated government loan deficiency payments (LDPs), with the LDP rate calculated as the difference between the loan rate and the simulated crop price whenever the simulated crop price was below the loan rate. The loan rates used for corn and soybean, respectively, were $71.65 and $176.00 Mg^{-1}, which were the

2008 loan rates for Stevens County, MN (USDA-FSA, 2008). Crop prices were adjusted to include quality discounts for low test weights with prices reduced according to the schedule in Table 2. To focus primarily on production-related risks, no other government payments, and no crop insurance payments or expenses were included in the risk analysis.

We use stochastic efficiency with respect to a function (SERF) analysis (Hardaker et al., 2004) to facilitate comparisons among tillage systems over a range of risk attitudes. The SERF method is a graphical method for comparing risky alternatives by calculating certainty equivalents (CEs) over a range of risk attitudes. The CE value is the amount of certain payoff an individual would require to be indifferent between that payoff and the risky alternative. For a risk-averse individual, this amount is less than the expected value of the risky alternative, and for a risk-neutral individual, this amount is equal to the expected value of the risky alternative. Comparing the CE value of risky alternatives at a specified risk aversion (RA) level gives an ordinal ranking of preferred alternatives, with alternatives having higher CE values preferred to those with lower CE values. In comparing two risky alternatives, the magnitude of the difference between CE values at a specified RA level is known as the risk premium and represents the minimum certain amount that would have to be paid to an individual in order for the individual to be willing to switch from the less risky alternative to the more risky alternative (Hardaker et al., 2004). For this analysis we used the SERF procedure in SIMETAR to calculate CE values using a negative exponential utility function for absolute RA levels ranging from 0 (risk neutral) to 0.0075 (extremely risk averse).

Statistical Analysis

Field treatments were arranged in a randomized complete block design with five replications. Crop yields, grain moisture content at harvest, grain test weight, and net returns were analyzed using SAS PROC MIXED (SAS Institute, 2006). Replications and years and their interactions were treated as random effects, with tillage treatments as fixed effects. Multiple comparison tests for differences among treatment means were identified using the Tukey-Kramer adjustment and a significance level of $P = 0.05$.

RESULTS AND DISCUSSION

Growing season precipitation and growing degree days (base 10°C) are shown in Table 3. Growing season precipitation

Table 2. Crop price discount for low test weight of grain for corn and soybean.

Test weight range		Price discount	
Min	Max	Corn	Soybean
kg m⁻³		$ Mg⁻¹	
605	618	5.91	2.57
618	631	4.72	2.20
631	643	3.54	1.84
643	656	2.36	1.47
656	669	1.57	1.10
669	682	0.79	0.73
682	695	0.39	0.37
695		0.00	0.00

Table 3. Growing season (May–September) precipitation and growing degree days (GDD, base 10°C) departures from normal for 1997–2003, planting and harvest dates at Morris, MN.

			Plant date	Harvest date	
Year	Precip.	GDD	Corn and soybean	Soybean	Corn
	mm	°C			
30-yr normal	412	1296			
1997	–45	–22	12 May	23 Sept.	8 Oct.
1998	–26	114	15 May	21 Sept.	29 Sept.
1999	128	–29	29 April	29 Sept.	13 Oct.
2000	–58	–47	21 May	28 Sept.	10 Oct.
2001	7	83	30 April	3 Oct.	23 Oct.
2002	–22	86	6 May	2 Oct.	14 Oct.
2003	–4	13	29 April	30 Sept.	7 Oct.

Table 4. Corn and soybean average annual production costs for 1997–2003 based on 2008 input prices, and comparison of rotation average total cost with total cost based on 2003–2007 average input prices.

	NT†	MP	CP	Fall RM	Fall RM + ST	Spring RM	Spring RM + ST	Fall RM + Subsoil
					$ ha^{-1}			
Corn costs								
Labor	17	28	24	20	21	20	21	21
Repairs	19	29	23	20	22	20	22	22
Diesel fuel	31	65	50	35	49	35	49	53
Seed, fertilizer, herbicide	734	734	734	734	734	734	734	734
Interest	19	22	21	20	21	20	20	21
Drying fuel	158	151	140	155	151	147	152	152
Total operating cost	979	1030	992	985	999	976	999	1004
Machinery depreciation	49	79	68	52	70	52	70	78
Machinery overhead	36	62	52	39	53	39	53	60
Total cost	1064	1171	1112	1076	1121	1067	1121	1142
Soybean costs								
Labor	16	30	26	19	20	19	20	20
Repairs	16	28	23	18	19	18	19	19
Fuel	28	66	54	31	45	31	45	49
Seed, fertilizer, herbicide	251	251	251	251	251	251	251	251
Interest	7	11	10	8	9	8	8	9
Drying fuel	4	3	3	6	3	4	3	3
Total operating cost	322	389	365	333	347	330	346	352
Machinery depreciation	40	75	66	43	61	43	61	68
Machinery overhead	30	61	53	33	46	33	46	54
Total cost	392	525	485	408	454	406	453	474
Rotation average costs								
Labor	16	29	25	20	21	20	21	21
Repairs	17	28	23	19	20	19	20	20
Fuel	29	66	52	33	47	33	47	51
Seed, fertilizer, herbicide	493	493	493	493	493	493	493	493
Interest	13	17	15	14	15	14	14	15
Drying fuel	81	77	71	81	77	75	77	78
Total operating cost	650	709	679	659	673	653	673	678
Machinery depreciation	44	77	67	47	65	47	65	73
Machinery overhead	33	61	53	36	49	36	49	57
Total cost	728	848	798	742	787	736	787	808
Total cost (2003–2007 prices)	506	609	569	519	558	515	558	577

† NT, no-till; MP, moldboard plow; CP, chisel plow; Fall RM, fall residue management; Spring RM, spring residue management; ST, strip-tillage.

ranged from 14% lower than normal in 2000 to 31% higher than normal in 1999. Growing season growing degree days ranged from 4% lower than normal in 2000 to 9% higher than normal in 1998. It is important, particularly for the risk analysis, that observations included a range of precipitation and temperature conditions, both higher and lower than normal. The higher growing degree days in 1998 may have contributed to higher corn and soybean yields observed in that year. However, higher growing degree days did not necessarily result in higher corn yields, as higher corn yields were also observed in 2000, although growing season precipitation and growing degree days were both lower than normal.

Corn and soybean production costs based on 2008 input prices for each of the tillage systems are shown in Table 4. The MP system had the highest total costs, and the NT system had the lowest total costs for both corn and soybean production. For the corn-soybean rotation, the NT system required 43 and 35% ($13 and $9 ha^{-1}) less labor than the MP and CP systems, respectively. The NT system also required 55 and 43% ($36 and $22 ha^{-1}) less diesel fuel than the MP and CP systems, respectively. However, the NT system required 6% ($4 ha^{-1}) more drying fuel than the MP system, and 14% ($10 ha^{-1}) more drying fuel than the CP system. Costs for the ST systems were comparable with the CP system, with the ST systems

having slightly lower costs for labor, repairs, and diesel fuel, but higher drying costs than CP. An exception is the Fall RM + Subsoil treatment, which had higher diesel fuel requirements than CP for corn production. Since the same seed, fertilizer, and herbicide applications were used across all treatments, there were no differences among tillage systems for these costs. However, these costs represent a large portion of the total production costs for each treatment, ranging from 58% of total production costs for the MP system to 68% of total production for NT. So, any differences in seed, fertilizer, and herbicide use among tillage systems could have a substantial effect on profitability. It has often been observed that economic optimum N fertilizer rates may differ among tillage systems (Stecker et al., 1995; Kwaw-Mensah and Al Kaisi, 2006; Archer et al., 2008); however, the design of this study did not allow for determination of optimum fertilizer rates for each tillage system. While higher herbicide costs have been identified as cause for reduced income in NT systems (Martin et al., 1991), weed control was observed to be good for all tillage systems in this study without increasing herbicide applications in the NT and ST treatments relative to the conventional tillage treatments.

Based on 2008 input prices, rotation average total costs were $120 and $70 ha^{-1} lower for NT than for MP and CP, respectively, with total costs for the ST alternatives generally

Table 5. Average crop yields, grain moisture content at harvest, test weight, and rotation average net returns for each tillage treatment averaged over 1997–2003.†

	Corn			Soybean			Net return 2007–2008 prices‡	Net return 2003–2007 prices§
	Yield	Moisture	Test weight	Yield	Moisture	Test weight		
	Mg ha⁻¹	g kg⁻¹	kg m⁻³	Mg ha⁻¹	g kg⁻¹	kg m⁻³	$ ha⁻¹	$ ha⁻¹
NT	9.8a¶	251.4a	669d	3.0a	131.8a	723a	557a	369ab
MP	10.0a	242.9ab	686ab	3.1a	123.8a	725a	472b	291d
CP	10.0a	235.6b	690a	3.1a	123.0a	722a	522ab	331c
Fall RM	10.1a	245.6a	681abc	3.0a	135.8a	716a	564a	372a
Fall RM + ST	10.1a	242.7ab	685abc	3.0a	123.9a	725a	519ab	332bc
Spring RM	9.6a	244.6ab	676cd	2.9a	128.1a	728a	525a	344abc
Spring RM + ST	9.9a	245.2a	679bcd	3.0a	124.8a	726a	514ab	329c
Fall RM + Subsoil	10.0a	243.5ab	684abc	3.1a	124.6a	726a	515ab	326cd

† CP, chisel plow; Fall RM, fall residue management; MP, moldboard plow; NT, no-till; Spring RM, spring residue management; ST, strip-tillage.

‡ Net return based on 2007 crop prices and 2008 prices for diesel, LP, seed, herbicides and fertilizer.

§ Net return based on 2003–2007 average prices for corn grain, soybean grain, diesel, LP, seed, herbicide, and fertilizer.

¶ Values with the same letter within each column not significantly different at the 0.05 probability level.

intermediate. Again, an exception was Fall RM + Subsoil which had total costs $10 ha⁻¹ higher than CP. Based on 2003–2007 average input prices, rotation average total costs were 28–32% ($221–239 ha⁻¹) lower than with 2008 input prices, and the cost advantage for NT was reduced to $103 and $63 ha⁻¹ compared to MP and CP, respectively (Table 4).

No significant differences between average grain yields were detected among tillage treatments for either corn or soybean (Table 5). This is similar to observations of Vetsch and Randall (2002), but differs from observations of Vetsch and Randall (2004) that corn grain yields under CP were significantly higher than under NT. Average corn grain moisture content at harvest was 15, 10, and 9 g kg⁻¹ higher for the NT, Fall RM, and Spring RM + ST, respectively than for CP (Table 5). This was reflected in the higher grain drying costs for these treatments. Vetsch et al. (2007) observed a similar effect with lower corn grain moistures observed under rotational CP tillage for soybean versus NT. Although these differences could potentially be reduced by delaying harvest under these systems, this could lead to higher risk of yield loss. Average corn grain test weights under CP were 21, 14, and 11 kg m⁻³ higher than for NT, Spring RM, and Spring RM + ST treatments, respectively. While CP does not significantly increase crop yields relative to NT and Spring RM + ST, it appears to result in higher corn grain quality as measured by moisture content at harvest and test weight, which reflects an earlier maturity of the corn crop. There were no tillage treatment differences in either moisture or test weight for soybean.

Average net returns for NT, Fall RM, and Spring RM were $85, 92, and 53 ha⁻¹ higher, respectively, than for MP based on 2007 crop prices and 2008 input prices (Table 5), and $78, 81, and 53 ha⁻¹ higher, respectively, than for MP based on 2003–2007 average prices. Since differences in grain yields and test weights among tillage treatments were minor, the differences in net returns can be attributed primarily to reductions in total operating costs of $51–59 ha⁻¹ (2008 input prices) combined with reductions in machinery ownership (depreciation and overhead) costs of $55–62 ha⁻¹. It is important to note that machinery ownership cost savings may not be entirely realized by producers who keep existing equipment (e.g., moldboard and tillage plow) as they transition into NT or ST alternatives.

It is also important to note that these costs are sensitive to farm size and may differ for different farm sizes.

While no significant differences in net returns were detected between CP and NT or any of the ST alternatives given 2007 crop prices and 2008 input prices, NT and Fall RM had significantly ($38–46 ha⁻¹) higher net returns than CP, Spring RM + ST, and Fall RM + Subsoil based on 2003–2007 average crop and input prices. These results are comparable with observations of Vetsch et al. (2007) that full-width tillage (fall CP for soybean, spring field cultivate for corn) resulted in net returns not significantly different from NT, ST, or zone-till (comparable with our Fall RM + Subsoil treatment) for a corn–soybean rotation in south-central Minnesota. However, our analysis shows that the results are sensitive to crop and input price assumptions.

Net return simulation summary statistics are shown in Table 6. Note the mean values differ slightly from the average net returns shown in Table 5, calculated with fixed prices even though the same average prices were used in the simulation analysis. This is due to the prices entering the net return calculations nonlinearly in calculating drying costs, test weight discounts, and LDP payments. The NT treatment had the highest mean net return and the lowest net return variability with CV of 27.2, while MP had the highest net return variability with CV of 31.4. Simulation analysis was also used to calculate the probability that net returns would not exceed a cash land rent payment of $269 ha⁻¹, which was the average cropland cash rent for Minnesota (USDA-NASS, 2008b). Fall RM had the

Table 6. Summary statistics of simulated net returns for each tillage treatment calculated from 1000 simulation iterations.

	Mean	SD	CV	Min.	Max.	P NR < CR‡
	—$ ha⁻¹—			—$ ha⁻¹—		
NT†	564	153	27.2	189	1082	0.008
MP	484	152	31.4	178	933	0.040
CP	525	143	27.3	182	944	0.010
Fall RM	573	159	27.7	195	1134	0.007
Fall RM + ST	537	152	28.4	212	1029	0.011
Spring RM	528	145	27.4	179	1059	0.010
Spring RM + ST	530	154	29.1	190	1052	0.013
Fall RM + Subsoil	522	153	29.4	172	1038	0.018

† CP, chisel plow; Fall RM, fall residue management; MP, moldboard plow; NT, no-till; Spring RM, spring residue management; ST, strip-tillage.

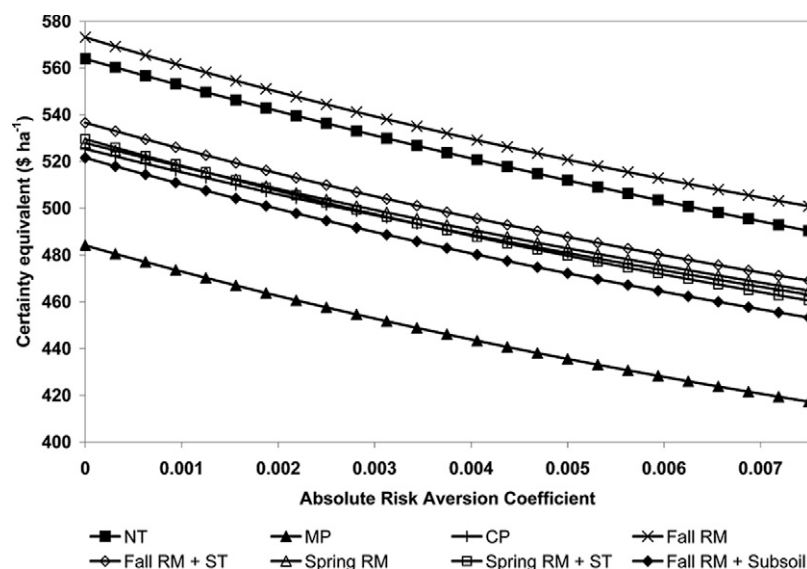‡ Probability of net return (NR) less than cash rent (CR) of $269 ha⁻¹.

Fig. 1. Certainty equivalent values for alternative tillage systems over an absolute risk aversion range of 0 to 0.0075 for a negative exponential utility function, and based on 2007 crop price and 2008 input price expectations. Tillage systems include no-till (NT), moldboard plow (MP), chisel plow (CP), fall residue management (Fall RM), Fall RM plus strip-till, spring residue management (Spring RM), Spring RM plus strip-till, and Fall RM plus subsoil.

lowest probability of failing to meet land rent at 0.7%, while the greatest risk of not meeting land rental costs occurred for MP at 4.0%.

Stochastic efficiency analysis shows CE values for Fall RM exceed those for all other tillage systems across the entire range of RA levels from 0 to 0.0075 (Fig. 1), so Fall RM would be the preferred alternative for producers who have risk preferences ranging from risk neutral to extremely risk averse. For any risk-neutral or risk-averse producer, CEs are ranked as: Fall RM > NT > Fall RM + ST > Spring RM + ST, Spring RM > CP > Fall RM + Subsoil > MP. Preferences for Spring RM + ST and Spring RM change as RA levels change, with Spring RM + ST dominant for RA levels 0–0.0013, and Spring RM dominant for RA levels 0.0013–0.0075. The CE values for Fall RM exceed those for NT by $8–11 ha^{-1} over the range of RA levels, indicating a relatively constant monetary advantage for Fall RM compared with NT regardless of risk preference. The CE values for Fall RM exceed those for CP and MP by $48 and $89 ha^{-1}, respectively, for a risk-neutral producer, but declines to $38 and $84 ha^{-1} for an extremely risk-averse producer, indicating the monetary advantage of Fall RM over both CP and MP declines slightly as RA grows.

To test the sensitivity of the risk analysis results to the expected crop and input price assumptions, the risk simulation was repeated with expected crop and input prices set at 2003–2007 average levels. In this simulation, the CEs were ranked as Fall RM > NT > Spring RM > Fall RM + ST > Spring RM + ST > Fall RM + Subsoil > MP (data not shown), so the results were not highly sensitive to the price expectation assumption. Only the relative rankings of Spring RM, Fall RM + ST, and Spring RM + ST changed, and these treatments were grouped closely together in the analysis using 2007–2008 price expectations. The risk analysis results are in contrast to analysis by Klemme (1985), which showed MP and CP tillage systems dominated NT for a corn-soybean rotation in

north-central Indiana. However, in that analysis it was noted that changes in yields or costs, such as reduced herbicide costs through improved weed control in NT, could lead to different rankings. Also, that analysis did not include effects of stochastic crop and input prices.

Producers have many risk management tools available to them, including different crop insurance products, futures, and options markets, forward contracting, and grain storage alternatives. Evaluation of these alternatives was beyond the scope of this analysis; however, the availability of these tools would certainly influence tillage system selection decisions. Excluding crop insurance payments underestimates crop income in years with low crop yields or prices. Inspection of yield observations during the period of study showed that there was generally not enough variability to result in a crop yield insurance payment. Assuming a crop insurance payment would be collected if an annual yield observation was <85% of the average yield for each tillage treatment across years, a payment would have been collected in 2002 for NT corn when corn yield was 79% of the average. Crop yield insurance payments would not have been triggered in any other year, or for any other treatment (data not shown), so omission of crop yield insurance had little effect on our results. However, many producers purchase crop revenue coverage, which protects against combinations of low yields and low prices. Our analysis underestimates crop income in years where these combinations occur. In addition, since large yield losses were not observed during the study period, we did not observe the type of risky event that producers may be most concerned about (a large reduction in crop revenue that occurs infrequently). Differences among tillage systems and the impacts of these events could change the risk preferences for these systems. For example, the observed higher corn grain moisture content and lower test weight for NT relative to CP may indicate slower crop maturity under NT and greater risk of yield loss due to early frost. However, the effects of an early

frost were not encountered during the study period, so the effects of this type of event could not be quantified.

Since the same planting date was used across all tillage systems, it is possible our results could be biased if significant tillage by planting date interactions exist. However, in a comparison of tillage systems for corn and soybean production in central Iowa, Perez-Bidegain et al. (2007) observed no significant grain yield interactions of tillage with planting date, even though timing of optimum planting conditions did vary by tillage system. This provides some support that our results would hold even if planting date varied by tillage system. Planting date differences among tillage systems might also have important economic and risk implications through limitations on labor availability and effects on timeliness of field activities (e.g., Archer and Gesch, 2003). While beyond the scope of this analysis, this is an area for future investigation.

CONCLUSIONS

Results from tillage systems research conducted over 7 yr on loam, clay loam, and silty clay loam soils for a corn-soybean rotation in west-central Minnesota showed no significant differences in crop yields among tillage systems. However, corn grain moisture at harvest was higher for NT, Fall RM, and Spring RM than CP, and corn test weight was lower for NT than for CP. Labor and diesel fuel use were lower for NT and all of the ST alternatives than for the conventional MP and CP systems. Rotation average net returns were lower for MP than for NT, Fall RM, and Spring RM, and, depending on price assumptions, net returns for CP were lower than for NT and Fall RM, or not significantly different from NT or any of the ST alternatives, indicating profitability could be increased or maintained through adoption of NT or ST compared with conventional systems. Economic risk analysis showed Fall RM would be the preferred alternative for any risk-neutral or risk-averse producer under uncertain yield and price conditions. Risk analysis also showed that NT and any of the ST alternatives, with the exception of Fall RM + Subsoil, would be preferred over the conventional systems by risk-neutral or risk-averse producers. Thus, ST and NT, along with their soil conservation benefits, may be economically viable alternatives to conventional tillage systems in the northern Corn Belt.

ACKNOWLEDGMENTS

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